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Can auscultatory blood pressure normative values be used for evaluation of oscillometric blood pressure in children?

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The aim of the study was to analyze whether auscultatory normative values (Fourth Task Force [4TF]) can be applied to blood pressure (BP) obtained by oscillometric devices. The authors performed a retrospective analysis of oscillometric office BP and ambulatory BP monitoring in 229 children (116 boys), median age 15.31 years. Office systolic BP (SBP) and diastolic BP (DBP) values were converted into *Z* scores using 4TF and oscillometric (German Health Interview and Examination Survey for Children and Adolescent [KiGGS]) reference values. There was good correlation between the two normative methods (r=0.9773 for SBP, r=0.9627 for DBP). Results from Bland-Altman test revealed only minimal differences in *Z* scores between 4TF and KiGGS for SBP, but a significant proportional error for DBP. 4TF and KiGGS *Z* scores were equally predictive of ambulatory hypertension. In conclusion, auscultatory and oscillometric normative data are interchangeable for SBP but not for DBP.

KEYWORDS
auscultatory normative values, blood pressure, children, oscillometric normative values

1 | INTRODUCTION

Measurement of blood pressure (BP) is an essential tool of physical examination in both children and adults. Traditionally, auscultatory/manual mercury sphygmomanometers have been used for office BP measurement, for which there are cardiovascular prognostic data in adults[1,2] and population-based normative data in children, ie, Fourth Task Force (4TF).[3,4] Recently, the use of automated oscillometric methods has become prevalent in clinical and epidemiological settings.[5] The oscillometric devices may overestimate or underestimate the auscultatory BP readings by approximately 3 to 5 mm Hg,[6,7] which may be negligible for adults but may be potentially important for children. Moreover, to compare the measured (absolute) BP with that from a healthy pediatric population, many pediatricians still apply the auscultatory 4TF normative data (based on first BP reading) for BP measured by oscillometric methods.[3] This approach may potentially yield incorrect BP percentiles or standard deviation scores (*Z* scores) and, consequently, incorrectly identify hypertensive children. At the same time, there are normative data for oscillometric BP devices available for various populations including Central European children,[8-13] which still await their wider use in clinical practice.

The aim of the study was to analyze whether the application of the traditional auscultatory normative data for BP measured by an oscillometric device yields equivalent percentiles/*Z* scores as the newer oscillometric normative data (German Health Interview and Examination Survey for Children and Adolescents [KiGGS]).[8] We also analyzed which normative data for the office BP better predicted hypertension on ambulatory BP monitoring (ABPM).

2 | PATIENTS AND METHODS

2.1 | Patients

We performed a retrospective chart review of children who were referred to the nephrology clinic in the Department of Pediatrics, University Hospital Ostrava, for assessment of hypertension. We selected 229 patients (116 boys) who had completed the office BP measurements and concurrently had 24-hour ABPM performed. No patient was treated with antihypertensive therapy at the time of the office and ABPM measurement. The main reasons for the investigation of BP were diabetes mellitus type 1 (n=84), elevated office BP (n=118), syncope or collapse (n=9), and various kidney diseases (n=18). All of these patients had normal renal function without any significant proteinuria except 15 diabetic patients with microalbuminuria.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the local ethics committee.

2.2 | Classification of patients

The patients were divided into normotensive and hypertensive groups based on their office BP (see section on the definition of office hypertension).

2.3 | Methods

2.3.1 | Patients' characteristic

At the time of the office and ABPM measurements, body height and weight were recorded in patients. Body mass index (BMI) was then calculated as kg/m^2, and BMI and height were converted into standard deviation (SD) scores (SDS), eg, *Z* scores, based on reference values for healthy Czech children (www.ojrech.cz/lesny/kompendium/foh.htm).

2.3.2 | Office BP measurement

Office BP was measured by a trained nurse on the same day as the ABPM (before initiating the ABPM device), according to current guidelines.[3] After 10 minutes of rest, the BP measurement was performed with an automatic oscillometric Omron M4-I device (Omron Healthcare Europe B.V., Hertogenbosch, The Netherlands), which is equivalent to the Omron 705IT device. (See: http://www.dableducational.org/sphygmomanometers/devices_1_clinical.html#ClinTable and http://www.dableducational.org/pdfs/equivalence_declarations/E15%20Omron%20M4-I%20ESH-BHS.pdf.) The oscillometric device was validated for BP measurement in children (http://www.dableducational.org/accuracy_criteria.html).[14] The measurements were performed on the right arm with the patient in the sitting position and the elbow at the level of the right atrium, using one of three cuff sizes (child: 6–12 cm, medium: 12–23 cm, or adults: 17–38.6 cm). The appropriate cuff size was determined by measuring the mid-arm circumference and was approximately 40% of the arm circumference (an inflatable bladder width[3]). Only the first measurement of BP was used for the analysis. The obtained absolute systolic BP (SBP) and diastolic BP (DBP) values were subsequently converted into SDS based on the two normative data sets: (1) the auscultatory 4TF normative values,[3] and (2) the German oscillometric pediatric BP normative values (KiGGS).[8]

2.3.3 | Definition of office hypertensive BP value and office hypertension

Office hypertensive values were defined as SBP or DBP values ≥95th percentile (eg, 1.645 SDS). As per definitions,[3] patients with SBP and simultaneously DBP values <95th percentile for age, height, and sex were regarded as having office normotension and the patients with SBP and/or DBP values ≥95th percentile (eg, 1.645 SDS) were regarded as having office hypertension.

2.3.4 | 24-Hour ABPM

In accordance with current guidelines (European Society of Hypertension 2009[4] and 2016[15]), ABPM was performed in all patients to confirm true/sustained, masked, or white-coat hypertension. ABPM was performed using a SpaceLabs 90217 oscillometric device (Spacelabs Healthcare, Snoqualmie, WA, USA). The monitor was programmed to measure BP every 20 minutes during the day (6 AM–10 PM) and every 30 minutes during the night (10 PM–6 AM). The parents and children were instructed to keep a diary of daily activities during the ABPM measurement. However, in order to compare our results with the normative values for ABPM,[16] we defined the daytime period as 8 AM to 8 PM (12 hours) and the nighttime period as 12 PM to 6 AM (6 hours).[16] The cuff size was determined by measuring the mid-arm circumference and was approximately 40% of the arm circumference. In all patients, the length of the cuff covered 100% of the arm circumference. The cuff was placed on the nondominant arm. The patients were instructed to avoid vigorous physical exercise during the ABPM measurement but to follow their usual daily activities. A minimum of 40 ABPM recordings were required to consider the ABPM as valid. For the analysis of the ABPM results, we used Chronos-Fit software 1.06.

For study purposes, the following linear ABPM parameters were obtained and analyzed: mean arterial pressure (MAP), SBP, and DBP measured over 24-hour daytime and nighttime periods. The average absolute values for MAP, SBP, and DBP for all time periods were subsequently converted into SDS values using the most recent normative values.[16]

2.3.5 | Definition of ABPM hypertension

Hypertension according to APBM was defined as ABPM SBP and/or DBP values ≥95th percentile (eg, 1.645 SDS) in any time period.[17] Similar to adults, the BP load in children was not included in the definition of ABPM hypertension.[18,19]

2.4 | Statistical analysis

Continuous variables were tested for normal distribution by computing the D'Agostino-Pearson omnibus normality test. The data are shown as mean±SD if normally distributed and as median and interquartile range (25th and 75th percentile) in cases of nonnormal distribution. The continuous variables in the patient groups were compared using *t* test (normally distributed data) or the Wilcoxon matched-pairs signed rank test (not normally distributed data). The categorical variables (proportion of patients between groups) were compared using chi-square or Fisher exact tests.

The correlation between BP SDS was examined using Pearson's correlation coefficient. The agreement between the two different normative BP methods was evaluated using Bland-Altman analysis, in which the difference between the two normative values is plotted against the mean of the two methods.[20]

TABLE 1 Patient Characteristics

Parameter	All Patients
Age, y	15.3 (12.9–16.8)
Female/male sex, %	113 (49.3)/116 (50.7)
Body height, cm	167 (157–176)
Body height (SDS)	0.13 (−0.8 to 0.7)
BMI, kg/m^2	20.95 (18.3–23.9)
BMI (SDS)	0.25 (−0.2 to 1.1)
Overweight, No. (%)	11 (4.8)
Obesity, No. (%)	38 (16.6)
SBP (absolute value), mm Hg	109.9±8.5
DBP (absolute value), mm Hg	75.7±10.3

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.
Values are expressed as median (interquartile range) or mean±standard deviation.
The conversion between standard deviation score (SDS) and percentiles is the following: −3 to −2 SDS=0.1 to 2.3 percentile; −2 to −1.88 SDS=2.3 to 3rd percentile; −1.88 to −1.645 SDS=3rd–5th percentile; −1.645 to −1.28 SDS=5th to 10th percentile; −1.28 to −1 SDS=10th to 15.9 percentile; −1 to −0.64 SDS=15.9th to 25th percentile; −0.64 to 0 SDS=25th to 50th percentile; 0 to 0.64 SDS=50th to 75th percentile; 0.64 to 1 SDS=75th to 84.1 percentile; 1 to 1.28 SDS=84.1 to 90th percentile; 1.28 to 1.645 SDS=90th to 95th percentile; 1.645 to 1.88 SDS=95th to 97th percentile; 1.88 to 2 SDS=97th to 97.7 percentile; and 2 to 3 SDS=97.7 to 99.9 percentile.

The feasibility of prediction of the ABPM hypertension from the office BP readings was analyzed using the receiver operator curve (ROC). The office SBP SDS and DBP SDS were used as predictors of the ABPM hypertension. The accuracy of prediction was classified using the area under the curve (AUC) for both SBP and DBP: AUC of 0.9–1=excellent, 0.8–0.9=good, 0.7–0.8=fair, 0.6–0.7=poor, and 0.5–0.6=fail.

The results were considered statistically significant if the *P* value was <.05. All statistical analyses were performed using the GraphPad Prism version 5.00 and 6.00 for Windows (GraphPad Software, San Diego, CA, USA; www.graphpad.com).

3 | RESULTS

Basic characteristics of the study population are given in Table 1. A total of 113 (49.3%) children were female. Of 229 children, only 38 (16.5%) patients were obese (BMI ≥95th percentile) and 11 (4.8%) were overweight (BMI >85th but <95th percentile). Mean SBP was 109.9±8.5 mm Hg and DBP was 75.7±10.3 mm Hg in the whole cohort of the patients.

The calculated SDS/*Z* scores of the office SBP and DBP values using the 4TF and KiGGS formula are shown in Table 2. The SBP *Z* scores calculated according to the 4TF normative values were significantly higher than *Z* scores obtained from the KiGGS normative standards (*P*=.0255). In contrast, the DBP *Z* scores were lower when using the 4TF (*P*=.0001; Table 2). The number of the office hypertensive SBP values using the KiGGS and 4TF were not significantly different, but the number of the office hypertensive DBP values were significantly higher using the KiGGS compared with the 4TF standards (81 and 50, respectively; Fisher exact test, *P*=.0019). In terms of office hypertension, the KiGGS formula yielded 144 hypertensive patients compared with only 136 patients defined as hypertensive based on the 4TF normative values (*P*<.001) (Table 2). These eight patients, who were

TABLE 2 Blood Pressure Results Using KiGGS and 4TF Normative Values

Parameter	KiGGS	4TF	*P* Value
Office SBP SDS	1.1±1.4	1.2±1.3	.0255
Office DBP SDS	1.0 (0–2.0)	0.9 (0.3–1.5)	.0001
No. of hypertensive office SBP values	82	84	1.0
No. of hypertensive office DBP values	81	50	.0019
No. of patients with office hypertension	144	136	<.0001
No. of patients with office systolic hypertension stage 1	9	6	.24
No. of patients with office diastolic hypertension stage 1	15	3	
No. of patients with office systolic hypertension stage 2	9	10	.16
No. of patients with office diastolic hypertension stage 2	9	3	

Abbreviations: DBP, diastolic blood pressure; 4TF, Fourth Task Force; KiGGS, German Health Interview and Examination Survey for Children and Adolescents; SBP, systolic blood pressure; SDS; standard deviation score.
Values are expressed as median (interquartile range) or mean±standard deviation.

labeled as hypertensive based on oscillometric normative methods but normotensive based on auscultatory method are shown in Table 3. All but one of these patients had diastolic hypertension (*Z* score >1.65) according to the oscillometric normative values; in contrast, all of these patients were labeled as normotensive based on auscultatory BP normative values.

A total of 22 patients were classified as having systolic ABPM hypertension and 24 patients as having diastolic ABPM hypertension. Overall, 46 patients were defined as having ABPM hypertension (either SBP or DBP >1.65 at any given time period). Based on ABPM and simultaneous office BP measurement, 39% of diabetic patients had normotension, 32% had white-coat hypertension, and 29% had true hypertension. The patients with kidney diseases were all normotensive. Of the remaining 127 patients, 4% had normotension, 42% had white-coat hypertension, and 10% had primary hypertension.

The correlation between the auscultatory and oscillometric SBP and DBP SDS values was significant (r=0.96; P<.0001 for both SBP SDS and DBP SDS; Figure 1).

Bland-Altman analysis revealed only a minimal difference in *Z* scores between the 4TF and KiGGS values for SBP (bias, −0.06±0.38; 95% limits of agreement, −0.82 to +0.70), but a significant proportional error for DBP; the KiGGS underestimated the DBP for DBP *Z* scores lower than 1.65 and overestimated DBP at DBP *Z* scores higher than 1.65 (bias, 0.18±0.60; 95% limits of agreement, −1.0 to +1.36) (Figure 2).

For ROC analysis, the 4TF SBP SDS/DBP SDS and KiGGS SBP SDS/DBP SDS were used as predictors of ABPM hypertension. The 4TF and KiGGS *Z* scores yielded similar ROC AUC for SBP/DBP (0.69±0.06 [*P*=.004]/0.64±0.06 [*P*=.024] and 0.69±0.06 [*P*=.0028]/0.66±0.06 [*P*=.012]; respectively), ie, they did not differ in the prediction of ABPM hypertension (Figure 3).

4 | DISCUSSION

The main findings of our study are as follows:

- The auscultatory and oscillometric normative data were nearly interchangeable for SBP evaluation, but significant differences (underestimation and overestimation) were noted for DBP.

TABLE 3 Characterization of Eight More Patients With Office Hypertension Using KiGGS Normative Values

Patient, No.	Age, y	Height, cm	Height SDS	Sex	SBP, mmHg	DBP, mmHg	KiGGS SBP–SDS	KiGGS DBP–SDS	4TF SBP–SDS	4TF DBP–SDS	4TF-KiGGS Difference SBP–SDS	4TF-KiGGS Difference DBP–SDS	ABPM Status	Hypertensive Status
6	13.41	158	0.14	Female	117	79	0.81	1.98	0.79	1.37	−0.01	−0.61	NT	WCH
8	10.70	136.9	−1.25	Female	118	74	1.78	1.73	1.63	1.24	−0,15	−0.48	NT	WCH
11	13.44	138.5	−3.48	Female	113	78	0.59	1.82	0.99	1.59	0.40	−0.24	NT	WCH
15	10.35	142	−0.24	Female	114	75	1.20	1.70	1.13	1.22	−0.08	−0.48	NT	WCH
79	7.29	120	−0.71	Male	109	74	1.43	1.99	1.19	1.46	−0.23	−0.53	HTN	HTN
104	8.93	148	1.95	Male	117	72	1.71	1.36	1.14	0.81	−0.57	−0.55	NT	WCH
137	7.27	133.5	1.36	Female	113	75	1.34	1.99	1.27	1.31	−0.07	−0.68	NT	WCH
198	8.81	137.2	0.29	Male	111	78	1.15	2.45	0.94	1.51	−0.21	−0.94	NT	WCH

Abbreviations: DBP, diastolic blood pressure; 4TF, Fourth Task Force; HTN, hypertension; KiGGS, German Health Interview and Examination Survey for Children and Adolescents; NT, normotension; SBP, systolic blood pressure; WCH, white-coat hypertension.
The conversion between standard deviation score (SDS) and percentiles is the following: −3 to −2 SDS=0.1 to 2.3 percentile; −2 to −1.88 SDS=2.3 to 3rd percentile; −1.88 to −1.645 SDS=3rd to 5th percentile; −1.645 to −1.28 SDS=5th to 10th percentile; −1.28 to −1 SDS=10th to 15.9 percentile; −1 to −0.64 SDS=15.9 to 25th percentile; −0.64 to 0 SDS=25th to 50th percentile; 0 to 0.64 SDS=50th to 75th percentile; 0.64 to 1 SDS=75th to 84.1 percentile; 1 to 1.28 SDS=84.1 to 90th percentile; 1.28 to 1.645 SDS=90th to 95th percentile; 1.645 to 1.88 SDS=95th to 97th percentile; 1.88 to 2 SDS=97th to 97.7 percentile; and 2 to 3 SDS=97.7 to 99.9 percentile.

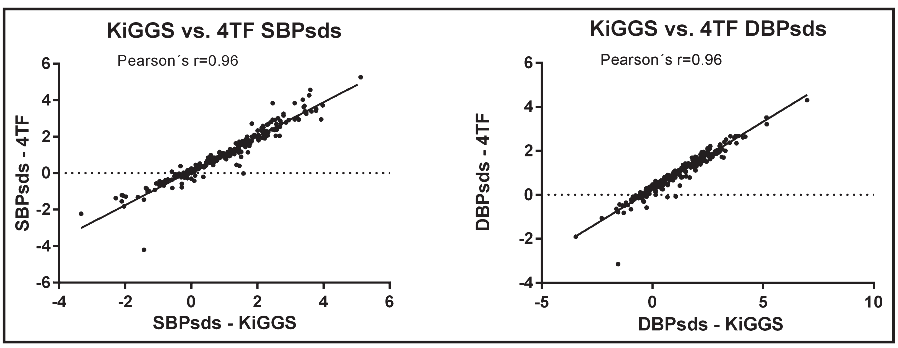

FIGURE 1 Correlation between the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) and the Fourth Task Force (4TF) formulas for systolic blood pressure (SBP) and diastolic blood pressure (DBP). sds indicates standard deviation score

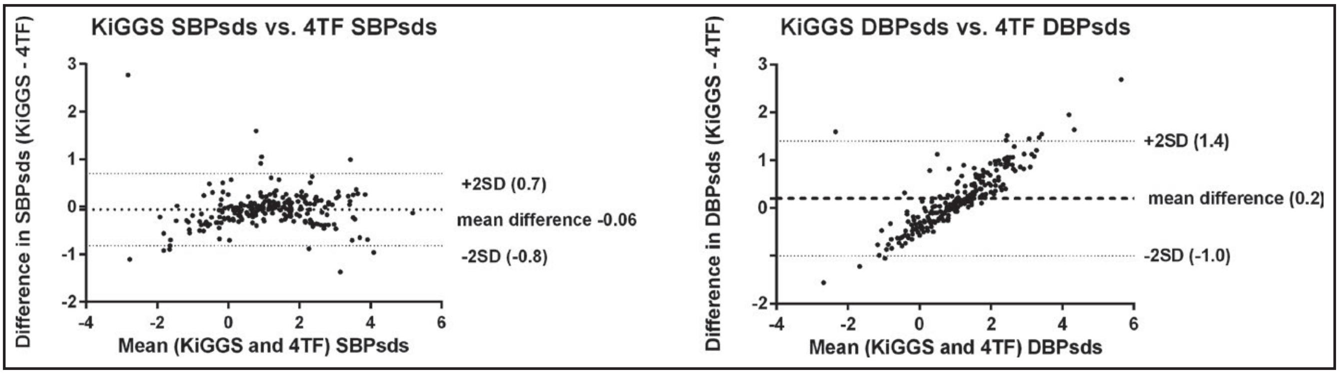

FIGURE 2 Bland-Altman analysis of German Health Interview and Examination Survey for Children and Adolescents (KiGGS) and Fourth Task Force (4TF) formulas for systolic blood pressure (SBP) and diastolic blood pressure (DBP). SD indicates standard deviation; sds, standard deviation score

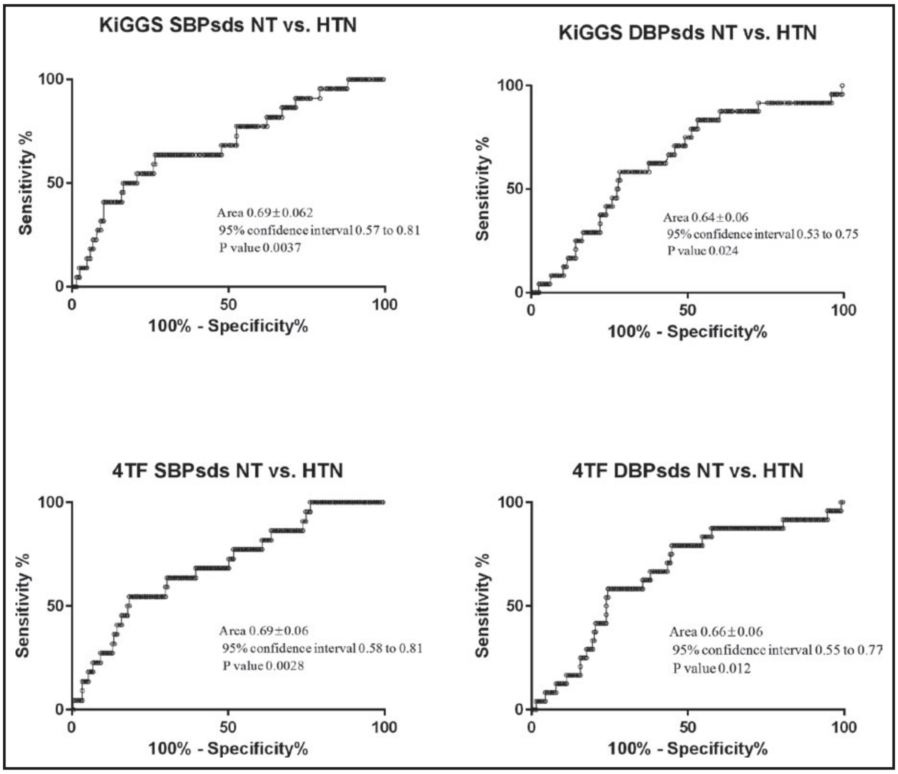

FIGURE 3 Receiver operating characteristic analysis in German Health Interview and Examination Survey for Children and Adolescents (KiGGS) and Fourth Task Force (4TF) formulas for systolic blood pressure (SBP) and diastolic blood pressure (DBP). AUC indicates area under the curve; HTN, hypertension; NT, normotension; SDS, standard deviation score

- The use of the KiGGS, eg, the oscillometric formula labeled significantly more children as hypertensive compared with the 4TF, eg, auscultatory formula, especially due to diastolic hypertension.
- Both methods were similar in the prediction of hypertension on ABPM.

In contrast to adult hypertension guidelines, pediatric guidelines still recommend the use of auscultatory BP measurement in children,[3,4,21–23] mainly to confirm that the BP is indeed elevated/abnormal. This is despite the fact that most pediatricians/family physicians use the automated (oscillometric) BP device in their offices. The widespread use of the automated BP devices presents at least two challenges: First, the BP machines measure MAP, whereas SBP and DBP are calculated by the software. As a result, the automated BP machines may yield slightly different BP values than the manual auscultatory devices.[6,7,24] Moreover, multiple measurements, usually 2 to 5 within several minutes, can be taken with the automated machines with the calculation of an average BP from multiple readings as opposed to a manual BP device, where only a limited number of BP measurements is performed (typically 1 to 3 per session).

Second, the recommended normative values for BP in children (4TF) are based on manual sphygmomanometer BP measurements (first reading).[3] It is therefore questionable whether these normative values can be applied to BP measured by automated machines.[25] Some authors argue in favor of using method-specific reference values,[11,26] whereas Chiolero and colleagues[27,28] suggest that if the oscillometric device is validated, there is no need for method-specific reference values, ie, auscultatory reference values can be used for BP values obtained by oscillometric device. To confirm this hypothesis, we embarked on a retrospective analysis comparing auscultatory and oscillometric BP normative values in children in whom BP was measured by a oscillometric device.

When applying the KiGGS and 4TF normative values to our children with BP measured using an oscillometric device, we found that the SBP *Z* scores were similar, whereas significant differences were noted for DBP. This is a novel finding and cannot be explained by previously described factors such as obesity and[8,11,13,29] number and order or average of BP measurements,[11] as these factors should influence both SBP and DBP. The differences in DBP may be, however, explained by differences in statistical approach for construction of the BP normative standard between 4TF and KIGGS[8] and regional BP differences with various effects on SBP and DBP.[10,11,25]

In addition, DBP is often difficult to measure with auscultatory devices and changes very little with age as compared with SBP, which significantly increases with age. We even speculate that DBP is more accurately measured/calculated with the oscillometric device compared with the auscultatory method relying on the fourth or fifth Korotkoff phenomenon (observer bias).[26] Consequently, a small change in absolute DBP value may result in a significant change in the DBP *Z* score. Last, the differences in DBP values may be potentially explained by various algorithms used in oscillometric devices.[26,30]

Of available oscillometric normative values,[8–13] we chose the German normative values (KiGGS)[8] for our study for the following reasons: (1) the central European population[10]; (2) the prevalence of obesity in the child population is similar in Germany and the Czech Republic[29]; (3) German oscillometric values are constructed based on sex, age, and height, ie, similar to the 4TF, whereas other oscillometric normative values are based on either age or height[4,12,31]; and (4) German oscillometric data have the broadest age range (from 3 to 17 years) and were constructed using the modified least mean square method (GAMLLS).

Interestingly, there are quite significant differences in BP *Z* scores between oscillometric BP reference values and auscultatory reference values (4TF).[8,10–12] These differences can be attributed to several factors such as demographics (ethnicity, various prevalence of obesity in children populations), method of BP measurement and differences in used BP readings as described above (eg, first vs second measurement, various averages), differences in statistical method to calculate percentiles, and differences in the time of publication/creation of reference values.[8,10,11,26,32]

4.1 | Study limitations

The precision of our BP readings may have been affected by a limited choice of BP cuffs provided by the Omron M4-I BP monitor (only three cuffs of various sizes were available, whereas the device used by Neuhauser and colleagues[8] included four different cuff sizes). However, we only included children older than 5 years who did not require special small BP cuffs. Other limitations are the retrospective design of our study, which does not allow cross-comparison of oscillometric with auscultatory measurement using both standards, and a relatively small number of patients. On the other hand, all of our patients had ABPM performed.

5 | CONCLUSIONS

For SBP obtained by oscillometric devices, both auscultatory and oscillometric normative data yielded similar *Z* scores/percentiles. However, there were significant differences in DBP *Z* scores using oscillometric and auscultatory normative data. We therefore recommend using oscillometric normative data for oscillometric devices and auscultatory normative data for auscultatory devices. Our data also support the pediatric recommendation that abnormal oscillometric office BP values in children should be remeasured with a standard auscultatory sphygmomanometer to confirm or rule out hypertension.

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CONFLICT OF INTEREST

The authors have nothing to disclose nor have any competing financial interest in relation to the work described.

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